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RESEARCH DEPARTMENT

Noise and vibration levels on the South Bank Site of the proposed Opera House and National Theatre

REPORT No. B-080
1963/49

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

NOISE AND VIBRATION LEVELS ON THE SOUTH BANK SITE OF THE PROPOSED OPERA HOUSE AND NATIONAL THEATRE

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SUMMARY

Measurements of airborne noise and ground vibration on the South Bank of the Thames between County Hall and Hungerford Bridge show that the roofs of the proposed National Theatre and Opera House should give a mean sound reduction of 69 dB with a slope not exceeding 7 dB per octave. Protection of the National Theatre from vibration will present considerable problems since it will be situated immediately above the Bakerloo tunnel; if possible the theatre should be moved to a position further from Hungerford Bridge.

1. INTRODUCTION

A noise and vibration survey was carried out between March 25th and March 28th 1963 inclusive to ascertain the maximum airborne noise and ground vibration levels to be expected in the positions to be occupied by the proposed Opera House and National Theatre. The original brief referred only to the Opera House site, but it was considered worthwhile to extend the measurements to include the site of the National Theatre which lies nearer to Hungerford Bridge and directly over the Bakerloo line connecting Waterloo and Charing Cross stations. The top of the upper Bakerloo tunnel lies approximately 46 ft (14 m) below the surface and the proposals for the theatre include a car park below ground, above which the main structure of the theatre will be built.

All measurements were made by recording the output of a microphone or an accelerometer and analysing them afterwards in the laboratory. This was necessary owing to the irregular and transient nature of the sounds being measured. For airborne noise a calibrated S.T. & C. 4021 microphone with omnidirectional characteristic was used, mounted in a windshield. The ground vibration was measured by means of a piezo-electric accelerometer. All analyses were carried out in octave bands having centre frequencies from 62 c/s to 8000 c/s.

2. POSITIONS OF MEASUREMENT

The site is shown in Fig. 1. It stretches along the river front from County Hall to Hungerford Bridge and is approximately 300 ft (90 m) wide and 800 ft (240 m) long. The first position for measurement was on the side of County Hall

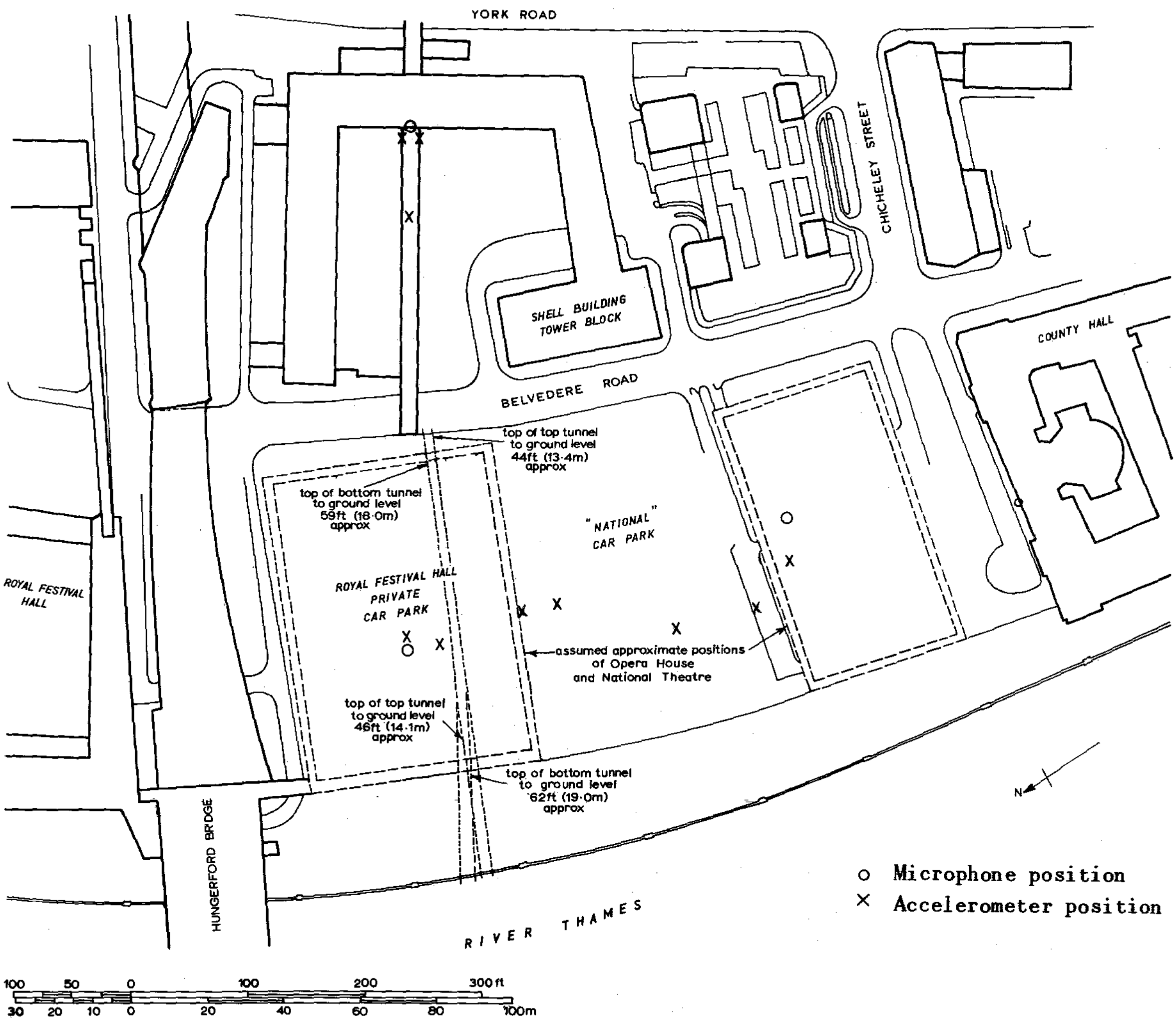
YORK ROAD
CHICHELEY STREET
SHELL BUILDING TOWER BLOCK
COUNTY HALL
BELVEDERE ROAD
top of top tunnel to ground level 44ft (13·4m) approx
top of bottom tunnel to ground level 59ft (18·0m) approx
"NATIONAL" CAR PARK
ROYAL FESTIVAL HALL
ROYAL FESTIVAL HALL PRIVATE CAR PARK
assumed approximate positions of Opera House and National Theatre
top of top tunnel to ground level 46ft (14·1m) approx
top of bottom tunnel to ground level 62ft (19·0m) approx
N
HUNGERFORD BRIDGE
RIVER THAMES
o Microphone position
× Accelerometer position
100 50 0 100 200 300ft
30 20 10 0 20 40 60 80 100m

Fig. 1 - Plan of South Bank Site for National Theatre and Opera House

facing the direction of Hungerford Bridge. A microphone was hung just below the sill of a second-floor window within 2 inches (5 cm) of the face of the building. In assessing the results 6 dB was subtracted from the pressure levels in order to compensate for the reflecting wall behind the microphone and thus make the results comparable with those from microphones in the other positions.

The second series of measurements was made in the Shell building in various positions over the course of the Underground tunnels. Most of these measurements were made in the basement at a depth of about 35 ft (11 m) below ground. A single measurement was also made on the lower ground floor but it was not possible to find other positions on the lower ground or ground floors sufficiently close to the line of the tunnels.

The third set of measurements was made in the Royal Festival Hall private car park, approximately in the middle of the proposed site of the National Theatre. The microphone was suspended at the top of an aerial mast mounted on a field-strength vehicle which was used as a laboratory for tests in this position and the next (Fig. 2). The accelerometer was fixed on one occasion to the top of the remains of a concrete pile and elsewhere to the tops of disused steel stanchions which had been cut off at ground level.

The fourth position for measurement was on the Opera House site at present occupied by a 'National' car park. The microphone was again used at the top of the

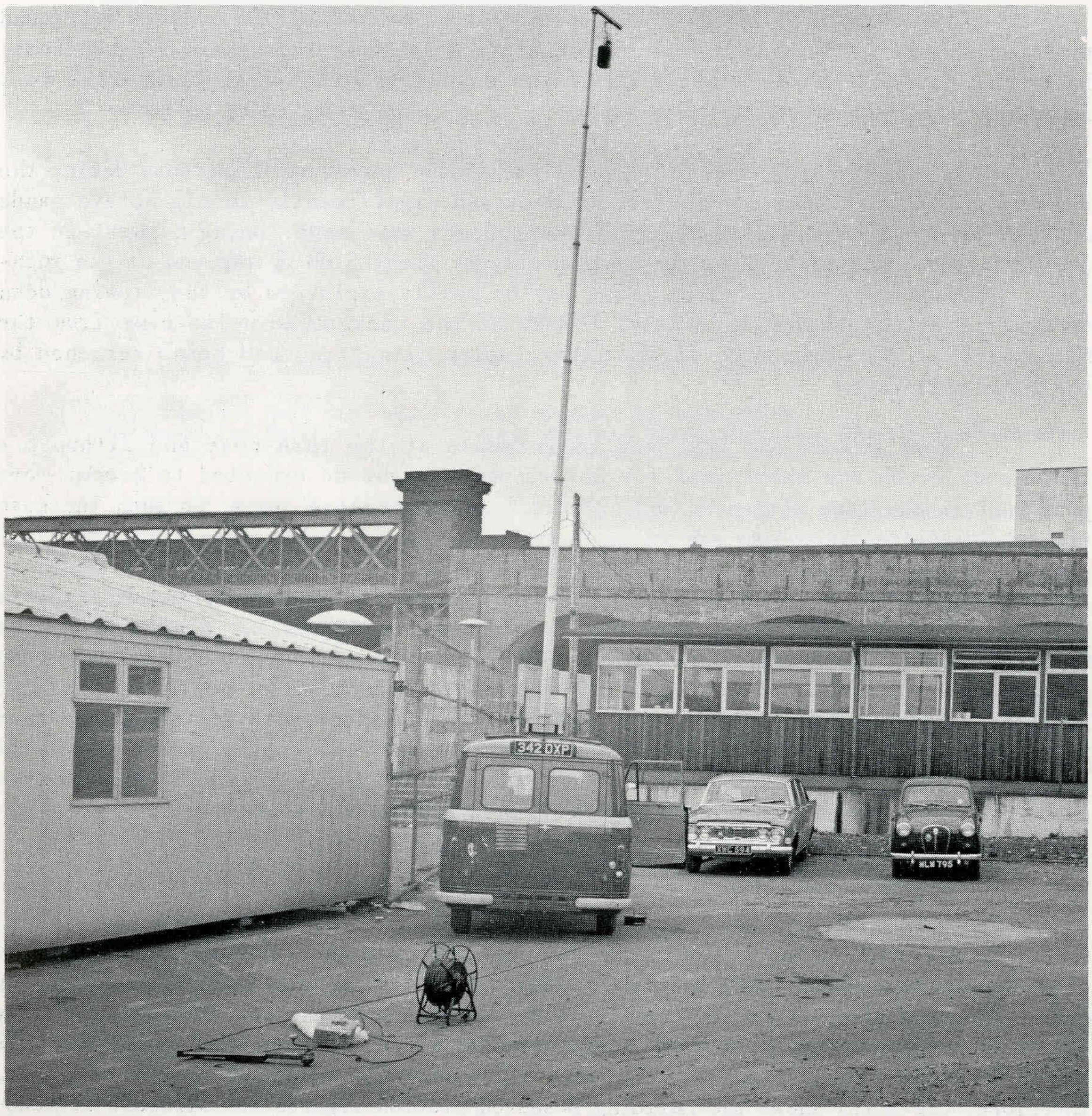

Fig. 2 - Photograph of part of Site, showing steel and brick sections of Hungerford Bridge, microphone on 30 ft (9·1 m) mast and accelerometer on top of disused stanchion in foreground

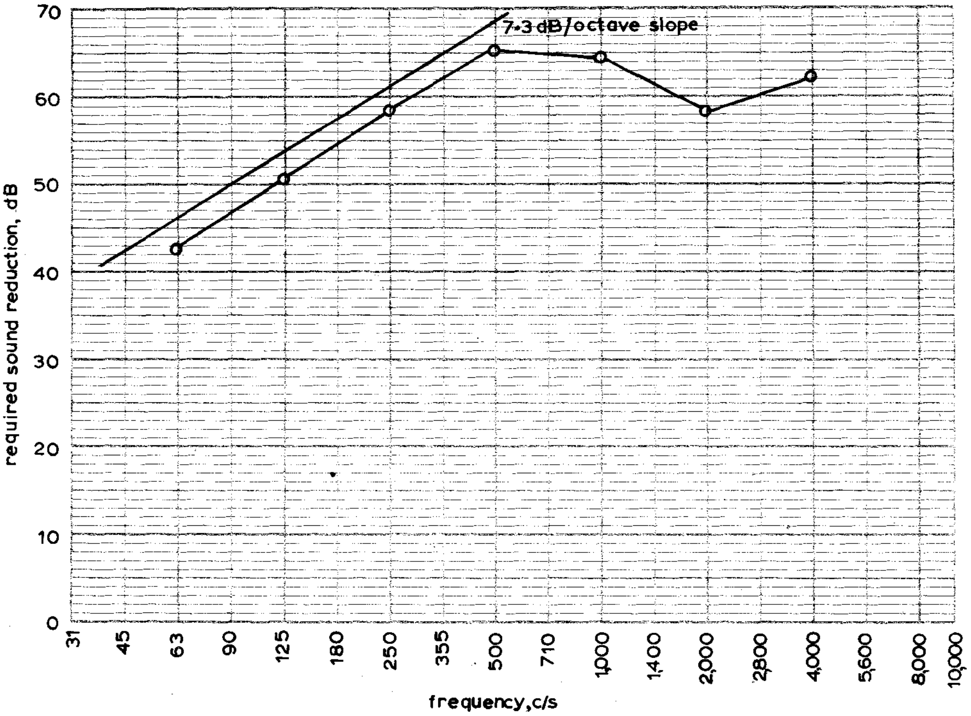

Fig. 4 - Sound reduction required from roofs of proposed Auditoria

4. RESULTS OF VIBRATION MEASUREMENTS

At the site of the National Theatre, underground and surface train vibration components were approximately equal. The maximum figures refer to two trains simultaneously and to account for the theoretical maximum of four trains, two underground and two surface at the same time, 3 dB should be added to the maximum vibration figures.

At the Opera House site the vibration at the surface of the ground is in general between 2 and 4 dB lower than at the theatre site, and therefore underground trains are all that need be considered.

In the basement of the Shell building the vibration is approximately 20 dB higher than at points on the surface of the Royal Festival Hall car park immediately over the tunnel. Measurements on the lower ground floor of the Shell building, which were unfortunately limited to one position only, showed a decrease of between 20 and 30 dB at the ends of the frequency range compared with the basement but only 15 dB between 250 and 1000 c/s. This result has not been fully explained but may be due to structural resonances at middle frequencies. Measurements in the Royal Festival Hall car park on the tops of steel stanchions gave, at low frequencies, similar results to those obtained on the tops of the concrete piles or foundations, but at higher frequencies reached very much larger amplitudes than on the concrete. This, again, has no obvious explanation but resonances in the steel are suspected. (A similar peak at high frequencies was recently found in measurements of ground vibration from piling operations when the accelerometers were mounted on the tops of steel stanchions.) Fig. 5 shows the maximum vibration levels at the three testing sites concerned.

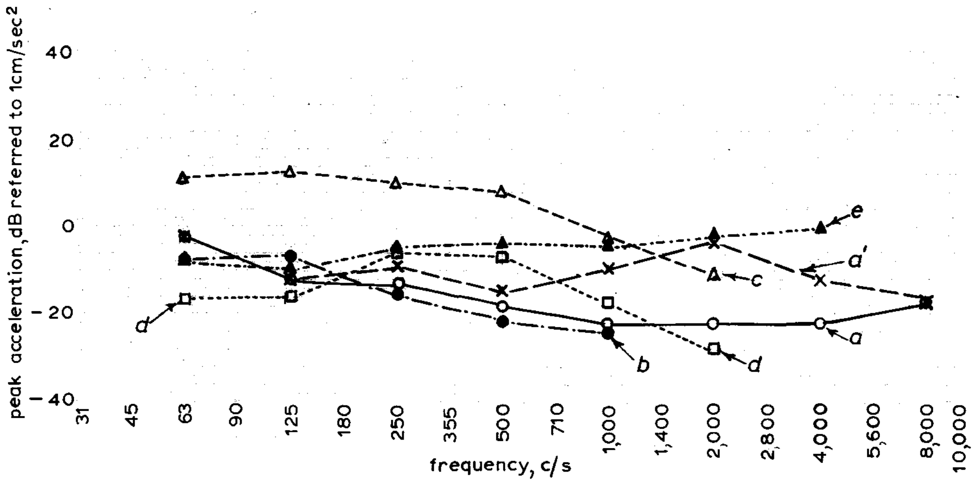

Fig. 5 - Maximum vibration accelerations in octave bands

(a) Royal Festival Hall Car Park (on pile cap)
(a') Royal Festival Hall Car Park (on stanchion)
(b) 'National' Car Park
(c) Shell Building Basement
(d) Shell Building Lower Ground Floor
(e) Maximum Tolerable Acceleration

The Shell building basement is only 11 ft (3·3 m) above the top of the Underground tunnel, with approximately 5 ft (1·5 m) of earth between the top of the tunnel and the concrete slab. The tunnel had to be held down during the excavation of the building to prevent it from rising by hydrostatic pressure from below and the intervening earth would be expected, by now, to be well consolidated by this pressure.

The maximum acceleration levels measured are in fact slightly greater than those due to Underground trains measured in B.H. Extension basement. Only if great care is taken in the design will it be possible to reduce Underground train noise to a sufficiently low level in the theatre, using compliant mountings and taking advantage of the presence of a car park between the tunnel and the main theatre. Fig. 5, curve (e), shows the maximum vibration level which is likely to be tolerable in the theatre or the Opera House and Table 2 shows the amount of isolation which must be provided.

No measurements could be made at depths corresponding to the foundation depth at the Opera House site but a vibration level intermediate between that in the Shell basement and the surface of the National car park can be expected. Fig. 6 shows, roughly to scale, a vertical section perpendicular to the line of the tunnels indicating the proposed positions of the theatre and the Opera House. From this drawing it appears that the distance of the Opera House is not great enough to assume that vibrations are entirely parallel to the surface and the vibration at the foundations will be appreciably higher than at the surface. Table 2 also shows estimated figures for the isolation required between the foundations of the Opera House and the auditorium.

5. CONCLUSIONS AND RECOMMENDATIONS

The only airborne sound which need receive consideration in designing the insulation of the roof and walls of the National Theatre and Opera House is that due

TABLE 2

Vibration levels due to trains

Band		1/1	2/1	3/1	4/1	5/1	6/1	7/1	8/1
Mid-Frequency c/s		62	125	250	500	1000	2000	4000	8000
N.C.20 S.P.L. dB. referred to 0•0002 dyne/cm^2		50	42	35	28	23	19	16	-
Permitted acceleration referred to 1000 c/s (Add 6 dB/octave)		+3	+1	0	-1	0	+2	+3	-
Permitted absolute vibration acceleration dB referred to 1 cm/sec^2(1 cm/sec^2 at 1 kc/s = +27 S.P.L.)		-1	-3	-4	-5	-4	-2	-1	-
Maximum measured acceleration in basement dB referred to 1 cm/sec^2		+12	+13	+10	+8	-3	-11	-	-
Required dB reduction at basement level (Theatre)	One train	13	16	14	13	1	-	-	-
	Two trains	16	19	17	16	4	-	-	-
Estimated reduction for Opera House (Mean between basement levels and National car park levels)	One train	4	6	2	-2	-	-	-	-
	Two trains	7	9	5	1	-	-	-	-

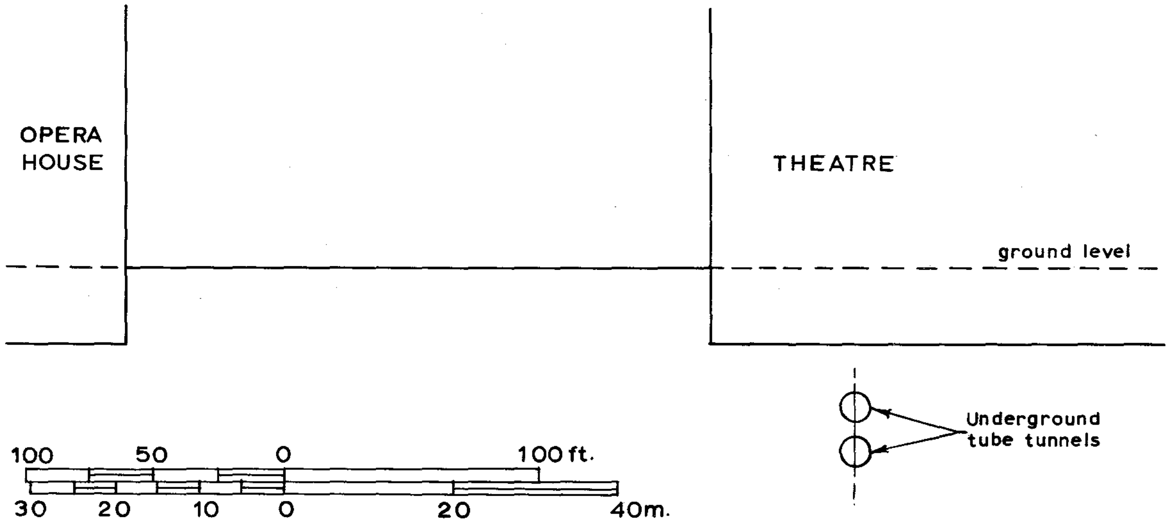

Fig. 6 - Section of Site showing relative positions of the two Auditoria and the Underground tunnels

to aircraft. Fig. 4 shows the required sound reduction. To meet the possibility of two aircraft simultaneously 3 dB should be added to the values shown. Wall insulation figures may be 3 dB lower than the curve since sound from aircraft overhead will fall tangentially on to them. This conclusion takes no account of any possible changes in the maximum level of aircraft noise which may occur in the future.

Vibration at foundation level of both buildings will be greater than could be tolerated for the floor of an auditorium. Only Underground trains need be considered in a design or in further surveys. The isolation of the National Theatre will present considerable problems and the maximum care must be exercised in design. If possible it would be highly desirable to move the theatre to a position further away from the Underground tunnel. Isolation of the Opera House to a sufficient extent should be a fairly simple matter.

In respect of ground vibrations, this survey can only be regarded as a guide for the specification of the building. Before a detailed design is attempted it will be necessary to make a far more extensive set of measurements including measurements in borings at different depths from the surface at the two sites.

6. REFERENCE

1. Beranek, L., 'Noise Control', Vol. 3, No. 1, p. 19, January 1957.

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